

WHAT IS CLAIMED AS THE INVENTION IS:

1. A method for forming a porous, open-pored inorganic material, comprising the steps of:

forming an amorphous inorganic powder material including amorphous powder particles having a mean particle size in a pre-selected range and packing the formed amorphous inorganic powder material to produce a packed amorphous inorganic powder; and

applying a sintering procedure to said packed amorphous inorganic powder which gives control over densification and includes choosing sintering temperatures and times sequentially that correspond to a first temperature and time duration during which the inorganic material is amorphous but displays an effective viscosity to develop significant sinter necks between adjacent powder particles by a viscous flow sintering mechanism while maintaining a desired open-pored structure, followed by a second temperature at which crystallization of the packed amorphous inorganic powder occurs and during which slower diffusion-related mechanisms control sinter neck growth and densification to give a substantially crystalline porous, inorganic structure.

2. The method according to claim 1 wherein the packed amorphous inorganic powder is continuously heated from the first temperature to the second temperature at an appropriate rate to achieve the substantially crystalline porous, inorganic structure.

3. A method according to claim 1 further including a step of infiltrating the formed three dimensional porous crystalline inorganic structure with an organic polymer or monomer of the polymer which is able to form strong primary chemical bonds with the porous, inorganic ceramic material to form a composite ceramic/polymer material.
4. A method according to claim 1 wherein the strong primary chemical bonds are one of ionic bonding and covalent bonding.
5. A method for forming an inorganic material into three dimensional structures, comprising the steps of:
- a) forming an amorphous inorganic powder material having a melting temperature, a crystallization temperature, a glass transition temperature and a glass softening temperature;
 - b) packing the formed amorphous inorganic powder material to produce a packed amorphous inorganic powder;
 - c) pre-sintering the packed amorphous inorganic powder for an appropriate time at a temperature greater than the lower of the glass transition temperature and the glass softening temperature and less than or equal to the crystallization temperature to produce a pre-sintered amorphous inorganic body; and
 - d) annealing the pre-sintered amorphous inorganic body to a final sintering temperature above the crystallization temperature and below the

melting temperature to form a three dimensional porous crystalline inorganic structure.

6. The method according to claim 5 wherein the amorphous inorganic powder material is amorphous calcium polyphosphate powder having particles in a pre-selected particle size range.

7. A method for forming porous calcium polyphosphate as claimed in claim 6 wherein the pre-sintering temperature of the packed calcium polyphosphate is at between 570 and 600°C.

8. A method for forming porous calcium polyphosphate as claimed in claim 7 wherein the packed calcium polyphosphate is heated to generally 500°C at a rate of generally 10°C per minute, maintained at 500°C for generally one hour and heated to between 570 and 600°C at a rate of 5°C per minute and then held at the maximum final sintering temperature for generally one hour.

9. A method for forming porous calcium polyphosphate as claimed in claim 8 wherein the final sintering temperature of the pre-sintered calcium polyphosphate is generally between 585 and 950°C.

10. A method for forming porous calcium polyphosphate as claimed in claim 7 wherein the final sintering of the pre-sintered calcium polyphosphate is to a

temperature of generally between 585 and 950°C.

11. A method for forming porous calcium polyphosphate as claimed in claim 6 wherein the final sintering of the pre-sintered calcium polyphosphate is at a temperature of generally between 585 and 950°C.

12. A method for forming porous calcium polyphosphate as claimed in claim 6 wherein the powder is packed to a packing density of generally 55%.

13. A method for forming porous calcium polyphosphate as claimed in claim 6 wherein the calcium polyphosphate powder has a predetermined maximum molecular chain length.

14. A method for forming porous calcium polyphosphate as claimed in claim 13 wherein the powder is producing by calcining calcium phosphate monobasic monohydrate to form a powder and melting the powder and maintaining the powder in a melted state between one and two hours, quenching the melted powders, and grinding the quenched melted powders to a predetermined size.

15. A method for forming porous calcium polyphosphate as claimed in claim 6 wherein the packed calcium polyphosphate powder is annealed in one of a ceramic and metallic mould to form a pre-sintered shape and the pre-sintered calcium polyphosphate body is removed from the mould and placed on one of a

plate and foil of a non reactive, precious metal during the annealing.

16. A method for forming porous calcium polyphosphate as claimed in claim 6 wherein the calcium polyphosphate powder is packed and annealed in a non-reactive platinum or Pt-Rh mould to the final sintering temperature.

17. A method for forming porous calcium polyphosphate as claimed in claim 6 wherein the calcium polyphosphate powder further includes trace amounts of metallic element dopants.

18. A method for forming porous calcium polyphosphate as claimed in claim 17 wherein the metallic element is selected from the group consisting of titanium, magnesium, zirconium, iron, aluminum, cobalt, tantalum, silicon, nickel, copper, potassium and sodium.

19. A method for forming a three dimensional porous crystalline inorganic structure as claimed in claim 5 wherein the amorphous inorganic powder material formed in step a) includes forming the amorphous inorganic powder material doped with an effective dopant for altering a rate of crystallization of the amorphous inorganic powder material.

20. A method for forming a three dimensional porous crystalline inorganic structure as claimed in claim 19 wherein the dopants are one or more metallic

elements.

21. A method for forming a three dimensional porous crystalline inorganic structure as claimed in claim 20 wherein the metallic element is selected from the group consisting of titanium, magnesium, zirconium, iron, aluminum, cobalt, tantalum, silicon, nickel, copper, potassium and sodium.

22. A method for forming a three dimensional porous crystalline inorganic structure as claimed in claim 21 wherein the metallic dopant is present as an ion and is selected from the group consisting of cations Na^+ , K^+ , Ti^{4+} , Mg^{2+} , Zr^{2+} , Fe^{2+} , Fe^{3+} , Al^{3+} , Co^+ , Ta^{5+} , Ni^{2+} , Cu^{1+} , Cu^{2+} and Si^{4+} .

23. A method for forming porous calcium polyphosphate as claimed in claim 6 wherein the amorphous calcium polyphosphate powder material formed in step a) includes forming the amorphous calcium polyphosphate powder doped with a pre-selected amount of an effective dopant for altering the processing conditions and/or the final chemical or physical properties of the formed porous calcium polyphosphate.

24. A method for forming a porous calcium polyphosphate structure as claimed in claim 23 wherein at least one of the processing conditions which is altered by the presence of the effective dopant is a rate of crystallization of the amorphous inorganic powder material.

25. A method for forming a porous calcium polyphosphate structure as claimed in claim 23 wherein the dopants are one or more metallic elements.
26. A method for forming a porous calcium polyphosphate structure as claimed in claim 25 wherein the metallic element is selected from the group consisting of titanium, magnesium, zirconium, iron, aluminum, cobalt, tantalum, silicon, nickel, copper, potassium and sodium.
27. A method for forming a porous calcium polyphosphate structure as claimed in claim 26 wherein the metallic dopant is present as an ion and is selected from the group consisting of Na^+ , K^+ , Ti^{4+} , Mg^{2+} , Zr^{2+} , $\text{Fe}^{2+ \text{ or } 3+}$, Al^{3+} , Co^+ , Ta^{5+} , Ni^{2+} , $\text{Cu}^{1+ \text{ or } 2+}$ and Si^{4+} .
28. A method for forming a porous calcium polyphosphate structure as claimed in claim 27 wherein the cations of Na^+ , K^+ , Ti^{4+} , and Mg^{2+} are present in oxides Na_2O , K_2O , TiO_2 and MgO respectively which are mixed into a calcium phosphate monobasic monohydrate powder used in step a) to produce the amorphous calcium polyphosphate powder material.
29. A method for forming porous calcium polyphosphate as claimed in claim 6 including controlling a relative humidity (RH) during application of the sintering procedure for controlling a temperature at which the amorphous calcium polyphosphate crystallizes.

30. A method for forming porous calcium polyphosphate as claimed in claim 29 wherein in step a) the amorphous inorganic powder material are formed having a particle size of between about 75 to about 105 μm , and wherein the packed amorphous calcium polyphosphate powder is pre-sintered by increasing the temperature at about 10°C/min to about 500°C and then 5°C/min to about 585°C and holding at about 585°C for about 1 hour under conditions of Relative Humidity in a range from about 30 to 40%, and then sintering by increasing the temperature at about 10°C/min to between 700 and 950°C and holding at this temperature for about 1 hour, then cooling to room temperature.

31. A method for forming a three dimensional porous crystalline inorganic structure as claimed in claim 5 including further steps of

mixing fine powder particles of the amorphous inorganic powder material with a fluid carrier, and immersing the formed three dimensional porous crystalline inorganic structure in the fluid carrier to allow the fine powder particles to be distributed throughout the pores and on the surface of the three dimensional porous crystalline inorganic structure following evaporation of the fluid carrier, and

sintering the three dimensional porous crystalline inorganic structure with the fine powder particles distributed therethrough at a sintering temperature and for a time being chosen to be above the glass softening or glass transition temperature but sufficiently low and for a short enough period of time to prevent the crystallization of the fine powder particles but to bond the fine powder

particles to the three dimensional porous crystalline inorganic structure.

32. The method according to claim 31 wherein the amorphous inorganic powder material is amorphous calcium polyphosphate powder, and wherein the fine powder particles of the amorphous inorganic powder material are fine calcium polyphosphate powder having a mean diameter less than about 50 μm to give a composite of crystalline and amorphous three dimensional porous calcium polyphosphate structure with regions that will degrade much more rapidly *in vivo* thereby releasing Ca^{2+} and PO_4^{3-} at faster rates from these regions while still retaining the initial integral porous calcium polyphosphate structure.

33. The method according to claim 32 wherein the fluid carrier has a sufficiently low viscosity to be able to infiltrate into the porous calcium polyphosphate structure while not readily dissolving the calcium polyphosphate that can be removed by heating without leaving a residue that is not biocompatible.

34. The method according to claim 33 wherein the fluid carrier is selected from the group consisting of water and alcohols.

35. A method for forming a three dimensional porous crystalline inorganic structure as claimed in claim 5 further including a step of infiltrating the formed three dimensional porous crystalline inorganic structure with an organic polymer,

or monomers of the polymer, which is able to form strong primary chemical bonds with the porous, inorganic ceramic material to form a composite ceramic/polymer material.

36. A method for forming porous calcium polyphosphate as claimed in claim 6 further including the step of infiltrating the formed porous crystalline calcium polyphosphate structure with an organic polymer, or monomers of the polymer, the polymer being able to form strong primary chemical bonds between the polymer and the porous crystalline calcium polyphosphate.

37. A method according to claim 35 wherein the monomers are infiltrated into the three dimensional porous crystalline inorganic structure and thereafter polymerized to the polymer.

38. A method according to claim 37 wherein the monomers are polymerized by one of heat induced curing, free radical polymerization and light induced curing.

39. A method according to claim 35 wherein the organic polymer is selected so that it covalently binds to the three dimensional porous crystalline inorganic structure.

40. A method according to claim 35 wherein the organic polymer is selected

so that it ionically binds to the three dimensional porous crystalline inorganic structure.

41. A method according to claim 36 wherein the monomers are infiltrated into the porous crystalline calcium polyphosphate structure and thereafter polymerized to the polymer.

42. A method according to claim 36 wherein the organic polymer is selected so that it covalently binds to the three dimensional porous crystalline inorganic structure.

43. A method according to claim 36 wherein the organic polymer is selected so that it ionically binds to the three dimensional porous crystalline inorganic structure.

44. A method according to claim 36 wherein the composite material is biodegradable.

45. A method according to claim 36 wherein the composite material is biodegradable and resorbable.

46. A method for forming porous calcium polyphosphate as claimed in claim 36 including machining the resulting composite material to a desired shape and

form while retaining suitable mechanical strength and fracture resistance as a result of the good damage tolerance of the interpenetrating phase composite thereby minimizing micro-crack formation and growth during machining.

47. An inorganic/polymer composite material, comprising:

- a) a porous, inorganic material having void spaces therein; and
- b) an effective polymer infiltrated into the void spaces, the effective polymer being able to form strong primary chemical interatomic bonds between the polymer and the porous, inorganic material.

48. The inorganic/polymer composite material according to claim 47 wherein the porous, inorganic material is selected from the group consisting of calcium polyphosphate, Al_2O_3 , hydroxyapatite, MgO , ZrO_2 , PSZ ZrO_2 , SiO_2 -containing ceramics and glasses, calcium sulphate-based materials and porous concrete.

49. The inorganic/polymer composite material according to claim 48 wherein the porous, inorganic material is calcium polyphosphate, and wherein said polymer is a vinyl polymer.

50. The inorganic/polymer composite material according to claim 49 which is biodegradable.

51. The inorganic/polymer composite material according to claim 49 which is biodegradable and biocompatible.
52. The inorganic/polymer composite material according to claim 48 which is non-biodegradable and biocompatible.
53. The inorganic/polymer composite material according to claim 47 which is non- biodegradable.
54. The inorganic/polymer composite material according to claim 47 which is non-biodegradable and non-biocompatible.
55. The inorganic/polymer composite material according to claim 47 which is non-biocompatible.
56. A product produced by a method comprising the steps of:
- forming an amorphous inorganic powder material including amorphous powder particles having a mean particle size in a pre-selected range, packing the formed amorphous inorganic powder material to produce a packed amorphous inorganic powder; and
 - applying a sintering procedure to said packed amorphous inorganic powder which gives control over densification and includes choosing sintering temperatures and times sequentially that correspond to a first temperature and

time duration during which the inorganic material is amorphous but displays an effective viscosity to develop significant sinter necks between adjacent powder particles by a viscous flow sintering mechanism while maintaining a desired open-pored structure, followed by a second temperature at which crystallization of the packed amorphous inorganic powder occurs and during which slower diffusion-related mechanisms control sinter neck growth and densification to give a substantially crystalline porous, inorganic structure.

57. The product produced by the method according to claim 56 wherein the packed amorphous inorganic powder is continuously heated from the first temperature to the second temperature at an appropriate rate to achieve the substantially crystalline porous, inorganic structure.

58. The product produced by the method according to claim 56 further including a step of infiltrating the formed three dimensional porous crystalline inorganic structure with an organic polymer or monomer of the polymer which is able to form strong primary chemical bonds between the polymer and the porous, inorganic ceramic material to form a composite ceramic/polymer material.

59. A product produced by the method according to claim 56 wherein the strong primary chemical bonds are one of ionic bonding and covalent bonding.

60. A product produced by a method comprising the steps of:

a) forming an amorphous inorganic powder material, having a melting temperature, a crystallization temperature, a glass transition temperature and a glass softening temperature;

b) packing the formed amorphous inorganic powder material to produce packed amorphous inorganic powder;

c) pre-sintering the packed amorphous inorganic powder for an appropriate time at a temperature greater than the lower of the glass transition temperature and the glass softening temperature and less than or equal to the crystallization temperature to produce a pre-sintered amorphous inorganic body; and

d) annealing the pre-sintered amorphous inorganic body to a final sintering temperature above the crystallization temperature and below the melting temperature to form a three dimensional porous crystalline inorganic structure.

61. The method according to claim 60 wherein the amorphous inorganic powder material is amorphous calcium polyphosphate powder having particles in a pre-selected particle size range.

62. A method for forming porous calcium polyphosphate as claimed in claim 61 wherein the pre-sintering temperature of the packed calcium polyphosphate is at between 570 and 600°C.

63. A method for forming porous calcium polyphosphate as claimed in claim 62 wherein the packed calcium polyphosphate is heated to generally 500°C at a rate of generally 10°C per minute, maintained at 500°C for generally one hour and heated to between 570 and 600°C at a rate of 5°C per minute and then held at the maximum final sintering temperature for generally one hour.

64. A method for forming porous calcium polyphosphate as claimed in claim 63 wherein the final sintering temperature of the pre-sintered calcium polyphosphate is generally between 585 and 950°C.

65. A method for forming porous calcium polyphosphate as claimed in claim 62 wherein the final sintering of the pre-sintered calcium polyphosphate is to a temperature of generally between 585 and 950°C.

66. A method for forming porous calcium polyphosphate as claimed in claim 63 wherein the final sintering of the pre-sintered calcium polyphosphate is at a temperature of generally between 585 and 950°C.

67. A method for forming porous calcium polyphosphate as claimed in claim 62 wherein the powder is packed to a packing density of generally 55%.

68. A method for forming a three dimensional porous crystalline inorganic structure as claimed in claim 60 wherein the amorphous inorganic powder material formed in step a) includes forming the amorphous inorganic powder

material doped with an effective dopant for altering a rate of crystallization of the amorphous inorganic powder material.

69. A method for forming a three dimensional porous crystalline inorganic structure as claimed in claim 68 wherein the dopants are one or more metallic elements selected from the group consisting of titanium, magnesium, zirconium, iron, aluminum, cobalt, tantalum, silicon, nickel, copper, potassium and sodium.

70. An inorganic/polymer composite material, comprising a porous, inorganic material having voids spaces therein and an effective polymer infiltrated into the void spaces, the effective polymer being able to form strong primary chemical interatomic bonds between the polymer and the porous, inorganic material, the inorganic/polymer composite material being formed by a method comprising the steps of:

forming a porous open-pored inorganic structure having a pre-selected porosity; and

infiltrating an effective polymer into the open-pored inorganic structure, the effective polymer being able to form strong primary chemical interatomic bonds between the polymer and the porous, inorganic material.

71. A product produced by the method of claim 70 wherein the open-pored inorganic structure is formed by any one of laser ablation, drilling or diamond drilling and solid free form fabrication of an inorganic material.

72. The inorganic/polymer composite material according to claim 70 wherein the porous, inorganic material is selected from the group consisting of calcium polyphosphate, Al_2O_3 , hydroxyapatite, MgO , ZrO_2 , PSZ ZrO_2 , SiO_2 -containing ceramics and glasses, calcium sulphate-based materials and porous concrete.

73. A product produced by the method of claim 70 wherein the open-pored inorganic structure is formed by the steps of :

- a) forming an amorphous inorganic powder material, having a melting temperature, a crystallization temperature, a glass transition temperature and a glass softening temperature;
- b) packing the formed amorphous inorganic powder material to produce packed amorphous inorganic powder;
- c) pre-sintering the packed amorphous inorganic powder for an appropriate time at a temperature greater than the lower of the glass transition temperature and the glass softening temperature and less than or equal to the crystallization temperature to produce a pre-sintered amorphous inorganic body; and
- d) annealing the pre-sintered amorphous inorganic body to a final sintering temperature above the crystallization temperature and below the melting temperature to form a three dimensional porous crystalline inorganic structure.

74. The inorganic/polymer composite material according to claim 73 wherein the porous, inorganic material is calcium polyphosphate, and wherein said polymer is a vinyl polymer.

75. The inorganic/polymer composite material according to claim 74 which is biodegradable.

76. The inorganic/polymer composite material according to claim 74 which is biodegradable and biocompatible.

77. The inorganic/polymer composite material according to claim 74 for use as an implant for use in assisting bone fracture repair in mammals.

78. The inorganic/polymer composite material according to claim 77 wherein the implant is one of a fracture fixation plates, intramedullary rods, screws and pins.

79. An implant for use in assisting bone fracture repair, comprising:
an inorganic/polymer composite material in which the inorganic is porous calcium polyphosphate, and wherein said polymer is a polymer infiltrated into the is porous calcium polyphosphate which is selected to form strong primary

chemical bonds with the calcium polyphosphate and which is physiologically or biocompatible with mammals; and

the inorganic/polymer composite being shaped to form a selected implant structure.

80. The implant according to claim 79 wherein the implant is shaped to form one of a fracture fixation plates, intramedullary rods, screws and pins.